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TRANSPORTATION OF CITRUS FRUIT FROM PORTO RICO

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INTRODUCTION

The transportation of citrus fruit overland has received considerable attention in the United States. The work of Powell,[2] Tenny,[3] Ramsey,[4] and their coworkers[5] has made possible the shipping of these fruits long distances, with reasonable assurance that if the proper conditions are furnished they will be attractive and desirable for food upon arrival at the market. One of the important points brought out by these investigations was that the fruit during certain seasons could be shipped best to distant markets under refrigeration. Fruit carelessly handled or affected by disease was found to be less likely to decay before reaching the market if shipped under refrigeration. The lower temperatures furnished in iced cars also delayed the natural breaking down of the fruit. The work has been of great value to the citrus growers of this country by establishing the use of refrigeration for the transportation of citrus fruits.

The shipping of citrus fruit by water has not received the attention given to the land transportation of these fruits, doubtless owing to the fact that only a small part of this crop of the continental United

[1] The writers wish to acknowledge indebtedness to their associate, W. S. Graham, for valuable assistance rendered on the trips described herein.

[2] Powell, G. Harold, and others. The decay of oranges while in transit from California. U. S. Dept. Agr., Bur. Plant Indus. Bul. 123, 79 p., 26 fig., 9 pl. 1908.

[3] Tenny, L. S., Hosford, G. W., and White, H. M. The decay of Florida oranges while in transit and on the market. U. S. Dept. Agr., Bur. Plant Indus. Circ. 19, 8 p., 2 fig. 1908.

[4] Ramsey, H. J. Handling and shipping citrus fruits in the Gulf States. U. S. Dept. Agr., Farmers' Bul. 696, 28 p., 10 fig. 1915.

[5] Stubenrauch, A. V., and others. Factors governing the successful shipment of oranges from Florida. U. S. Dept. Agr. Bul. 63, 50 p., 26 fig., 15 pl. 1914.

States moves by water. This means of transportation for citrus fruit is becoming more important, however, not only from the outlying islands of the United States, but from California and Florida as a supplement to rail shipment. Until recently most of the citrus fruits shipped into or from this country by water were handled in ventilated holds or in regular cargo holds which were not refrigerated. There has always been more or less loss with this method of shipment, depending upon the condition of the fruit when shipped, the season of the year, the temperature maintained in the holds, and the methods of handling. It would seem that low temperatures combined with proper methods of handling the fruit would be as valuable in ocean as in land transportation. It was to determine the value of refrigeration on shipboard and to work out the best methods for loading and handling the fruit in refrigerated holds that the experiments described herein were undertaken. It was thought probable, also, that information gained as to the best methods for shipping citrus fruit would be applicable to the shipment of apples, pears, and other fruits both in intercoastal trade and for export.

EQUIPMENT AND CONDITIONS OF THE EXPERIMENTS

The investigations here described were conducted in cooperation with a steamship company operating between New York and Porto Rico, on a twin-screw steamer equipped for both freight and passenger service. The vessel makes the trip in approximately three and one-half days, completing a round trip to and from New York every three weeks. It arrives in San Juan on Wednesday forenoon and discharges its cargo, remaining there until Thursday night. It then proceeds around the island, calling at ports and discharging and receiving cargo, and returning to San Juan the following Tuesday or Wednesday morning, to finish loading. On Thursday it starts on the return trip to New York, where it arrives early Monday morning, leaving again for Porto Rico the next Saturday.

In this vessel five cargo-carrying compartments have been insulated and refrigerated for carrying fruit. The entire capacity of these holds was about 35,000 boxes of citrus fruit, using the standard Florida box as a unit of measurement. The insulation was heavy, consisting of 4 inches of cork, three layers of seven-eighths-inch matched lumber, and eight layers of paper, with a 3-inch air space between the first outer layer of boards and the ship's side. The hatches to these compartments were fitted with insulated covers, of construction similar to that of refrigerator doors, built in sections and fitted with gaskets, which were supposed to make them air-tight when the covers were in place.

The cooling system was a combination of brine and forced-air circulation, three ammonia compressors of 18 tons capacity furnishing the refrigeration. The insulated compartments were cooled by air forced over brine pipes, which were placed against and along the insulated sides of the compartments, extending the entire length and from floor to ceiling. A board partition, or apron, about 9 inches from the sides of the compartments formed a continuous duct through which air was circulated and in which the brine pipes were inclosed. This apron was pierced at regular intervals by a number

of small holes, to which were fitted sliding shutters which could be opened and closed at will to regulate the amount of air entering or leaving the compartments. The air was circulated over the brine pipes on either side and across the compartments athwartships by two large centrifugal fans connected in parallel, so that they might be used either together or separately. A series of dampers in the air

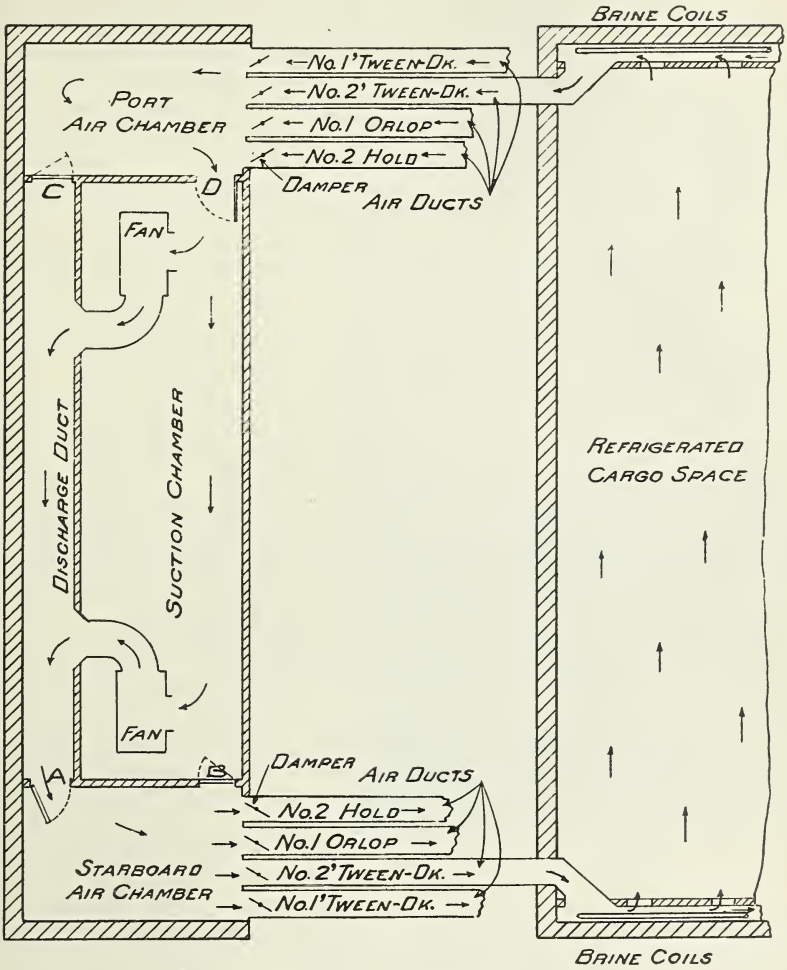

Fig. 1.—Diagram showing the operation of the fans and the air-circulating system in the forward part of the ship

ducts permitted the reversing of the air circulation across the holds. In the forward part of the ship the ducts formed by the aprons and the sides of the compartments, or holds, are connected by suitable ducts which open into air chambers situated on the port and starboard sides at the after end of No. 2 between-decks [6] (fig. 1). At the point of entrance into the air chambers these ducts are fitted with

[6] Commonly called "'tween-decks."

dampers and plugs, the manipulation of which controls the flow of air into the different holds. Two air passages extending athwartships connect the port and starboard air chambers. One of these serves as a common discharge chamber and the other as a common suction chamber for both fans, which are located in the suction chamber.

On referring to Figure 1 the method of operation for securing the circulation of air is obvious. To cause the air to circulate across the hold from port to starboard, the dampers B in the suction chamber and C in the discharge chamber are closed, and dampers D in the suction chamber and A in the discharge chamber are opened. This arrangement allows the fans to draw the air through the dampers D from the port ducts, which empty into the port air chamber, and discharge it under pressure into the discharge chamber, thence through the damper A into the starboard air chamber and into the ducts leading into the holds. On reaching these ducts in the holds formed by the apron and the ship's side the air is forced along the cold brine pipes and out into the hold through the small holes which pierce the apron. It then circulates across the hold and is drawn into the port-side ducts through the holes in the apron along the brine pipes into the port air chamber, thus completing the circuit. To reverse the direction of the air movement through the hold it is only necessary to regulate the appropriate dampers. As far as the writers have been able to learn, this is the first time that this type of installation has been used in the American fruit trade.

During the investigation, which continued from September to December, 1922, four consecutive test trips were made on this vessel, the first leaving New York in the middle of September and returning October 2, this being the first voyage the vessel made after the installation of its refrigerated fruit-carrying equipment.

As one purpose of this test was to determine the efficiency of this type of refrigeration equipment in carrying fruit, it was necessary to measure the fruit temperatures in different parts of the load, to take air temperatures at various points where the air entered and left the hold, and to determine the brine temperatures in the banks of brine coils back of the aprons, over which the air circulated before and after leaving the hold containing the fruit. The brine temperatures were taken in the usual way with mercurial thermometers placed in the incoming and outgoing brine pipes. The temperature of the air as it entered the fan chamber from the holds and as it went into the holds was taken with thermometers. The temperatures of both fruit and air within the holds were measured with electrical-resistance thermometers attached to cables, so arranged that readings of the temperature within the hold could be made without entering it. With these resistance thermometers it was possible to get both air and fruit temperatures in various parts of the hold.

CITRUS-FRUIT GROWING IN PORTO RICO

Citrus fruit in Porto Rico is grown on both sides of the island, and in some cases well into the interior. Around San Juan there are many orange and grapefruit groves which are well cultivated and cared for and have the advantage of modern packing-house facili-

ties. In some other parts of the island much of the fruit is not cultivated, but is grown as shade or windbreaks in connection with other crops. This fruit is usually not handled so carefully or packed so well as the cultivated fruit. The experimental work recorded here was confined largely to cultivated fruit.

Citrus fruit from all localities in Porto Rico is more or less affected with stem-end rot caused by *Diplodia natalensis*, according to determinations made by the Office of Fruit-Disease Investigations. Mann[7] has shown that the fruit does not carry well under ventilation. As the disease mentioned can be controlled to a considerable extent by keeping the fruit at low temperatures, it would seem to make refrigeration almost an essential in the transportation of citrus fruit from Porto Rico.

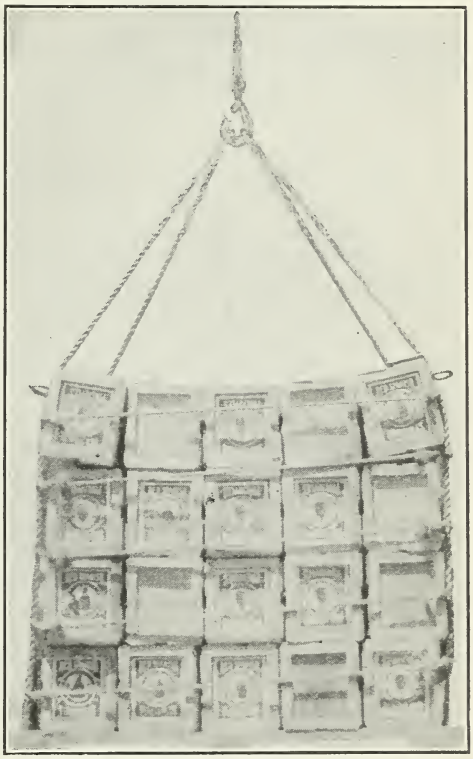

FIG. 2.—Sling used in loading citrus fruit and pineapples in Porto Rico

TAKING THE FRUIT ON THE SHIP

In these experiments the fruit was in some cases loaded directly from piers into the ship; in others, it was necessary to lighter it to the ship's side; then to lower it into the hold through the hatches or pass it in through ports in the ship's side. When loading directly from the pier through the side ports the fruit was either trucked or carried into the hold; in loading through the hatches the ship's tackle and slings were used. The particular sling employed in this work is known as the "aeroplane" sling (fig. 2). It consists of a rectangular platform fitted with ropes, which pass through each corner and through rings in the ends of the spreaders to the hook on the block of the up-and-down fall. The spreaders are pieces of 6-inch angle iron the length of a box of fruit, placed over the corners of the top box to take the lateral strain of the ropes, thus preventing them from cutting into the boxes when the sling is lifted into the air. The sling is also equipped with a net, extending from the spreaders to the floor of the platform. The aeroplane sling is a very good type for citrus fruit, as there is little danger of chafing or

[7] Mann, C. W. The handling of Porto Rican oranges, grapefruit, and pineapples. Porto Rico Insular Exp. Sta. Bul. 7, 59 p., 24 fig. 1914.

breaking the boxes and injuring the fruit with the ropes. The boxes are held securely, so that there is no danger of falling out unless the sling is inverted.

STOWING THE FRUIT

Unlike transportation by rail, little or no experimental work had been undertaken to determine the best methods of loading for ocean movement. The problem is more like stacking fruit in a precooling room or storage plant than loading in refrigerator cars. The results desired are practically the same as those sought in precooling rooms or refrigerator cars—to load as much fruit as possible in a given space and so arrange it that it can be cooled down quickly to a good refrigerating temperature. This, of course, means that it must be stowed so that air can circulate through the fruit to cool it. It is important, also, that the boxes of fruit be placed in the hold in such a way that they will not be thrown about by the motion of the ship and yet so that they can be readily unloaded at destination. In the experiments under consideration several methods of stowing were tested in an endeavor to find those best suited to the type of refrigeration employed on this ship.

Dunnage was used in order to secure air circulation and to test its value in bringing about better refrigeration and a quicker cooling of the fruit. The term "dunnage" is applied here to strips of board about 1 inch thick placed on the boxes as they are stacked in the hold, much as the stripping is placed on boxes in refrigerator cars.

Three different methods of placing dunnage were tried in the earlier experiments, two of which were abandoned. In the first method the dunnage was placed fore and aft, the fruit boxes being placed with their longitudinal axes athwartships. For rapid loading this necessitated very short pieces of dunnage, causing considerable loss of time. The next method was the use of long, broad strips of dunnage, the boxes being loaded with their longitudinal axes fore and aft, half the width of the dunnage overlapping the ends of the boxes. The stack, or height, was completed and the next stack placed in the same manner except that one end was forced under the overlapping dunnage in the preceding tier. It was thought that this method would conserve dunnage and give satisfactory results, but owing to the uneven stowage caused by the irregularities in the packages great difficulties were encountered in securing a uniform stack, and considerable space was lost. The second method was attempted primarily to save dunnage, but it was found that it was not economical because of the time consumed in stowing the fruit.

The third method and the one adopted for general use was that in which two pieces of dunnage were used across the ends of the boxes in each layer, the boxes being stowed with their longitudinal axes fore and aft and the dunnage athwartships. Although this increased the quantity of dunnage used, it reduced the labor and facilitated the speed and ease with which the fruit was stowed. It also made possible the use of narrower strips of dunnage.

To determine the practical advantage to be secured from the judicious use of dunnage so far as obtaining better refrigeration is

concerned, tests were made of three different methods: (1) Stacking the fruit with dunnage in every layer, (2) stacking with dunnage in every other layer, and (3) without dunnage.

THE FIRST TRIP

On the first trip from Porto Rico to New York with citrus fruit the loading began at Ponce on September 23. The day before the fruit was taken aboard the refrigeration machinery was started and the holds cooled down. Prior to this the air temperatures in the hold were 70° F. at the bottom and 78° at the top. The temperature of the fruit received at this point averaged 80.7°, and the average temperature of the fruit loaded from all five ports—Mayaguez, Aguadilla, Ponce, Arecibo, and San Juan—was 80.4° F. The fruit was loaded six layers high on this first trip.

Two holds were loaded, No. 2 between-decks and No. 1 between-decks. The arrangement of resistance thermometers for these two holds is shown in Figures 3 and 4. These illustrations show the locations at which air and fruit temperatures were taken in the hold. An attempt was made in installing these temperature-measuring instruments to get temperatures representing the extreme conditions in the hold and also to obtain as nearly as possible a complete story of the temperature changes in the various sections of the hold.

In cooling down the fruit it is necessary not only to take out the initial heat but to take care of any heat that may enter the hold through the insulation or through any openings. It is seldom possible to fill a hold completely at one port; therefore it is frequently necessary to open the hatches or the side ports after some fruit has been placed in the hold and is partially cooled down. Some data were obtained in these experiments on the effect of this opening of the hold so that warm air could enter after the hold had been refrigerated for some time. As shown in Figures 5 to 7, which give the average air, fruit, water, and brine temperatures on the trip, the fruit temperatures were slowly reduced. On the first reading (fig. 6), which took place 12 hours after loading was begun, the fruit showed an average temperature of approximately 74° F. At the end of the trip the average fruit temperature was 54°, a reduction of 20 degrees in a period of eight and one-half days, or about 2.35 degrees F. per day.

In Figure 7, which gives data on fruit loaded at San Juan only, the second reading showed a temperature of 82° F.; and in four days, the time from the first to the last reading, the temperature was reduced to 57°, a total of 25 degrees of heat removed from the fruit, or 6.25 degrees F. per day.

There is a difference of about 5 degrees in favor of the fruit in No. 1 between-decks, Figure 7, and No. 2 between-decks, Figure 6. Although the fruit in No. 2 between-decks was under refrigeration for a much longer period, the fruit in No. 1 between-decks shows a more rapid cooling, owing to the operation of the equipment.

Referring to Figures 5 and 6, it will be noted that the brine temperatures show considerable fluctuation, which affects the temperature of the air in the suction or mixing chamber and in turn the air entering the hold. It is noticeable that on the third day after load-

ing was begun the temperatures of the brine, air, and fruit rose markedly. This was caused by stopping the refrigerating machinery to defrost the coils and opening the holds at San Juan to load more warm fruit. The average temperatures of all the fruit rose to about 78° F., or only 2 degrees lower than the temperature of the fruit on the deck. This rise was due in part to placing resistance thermom-

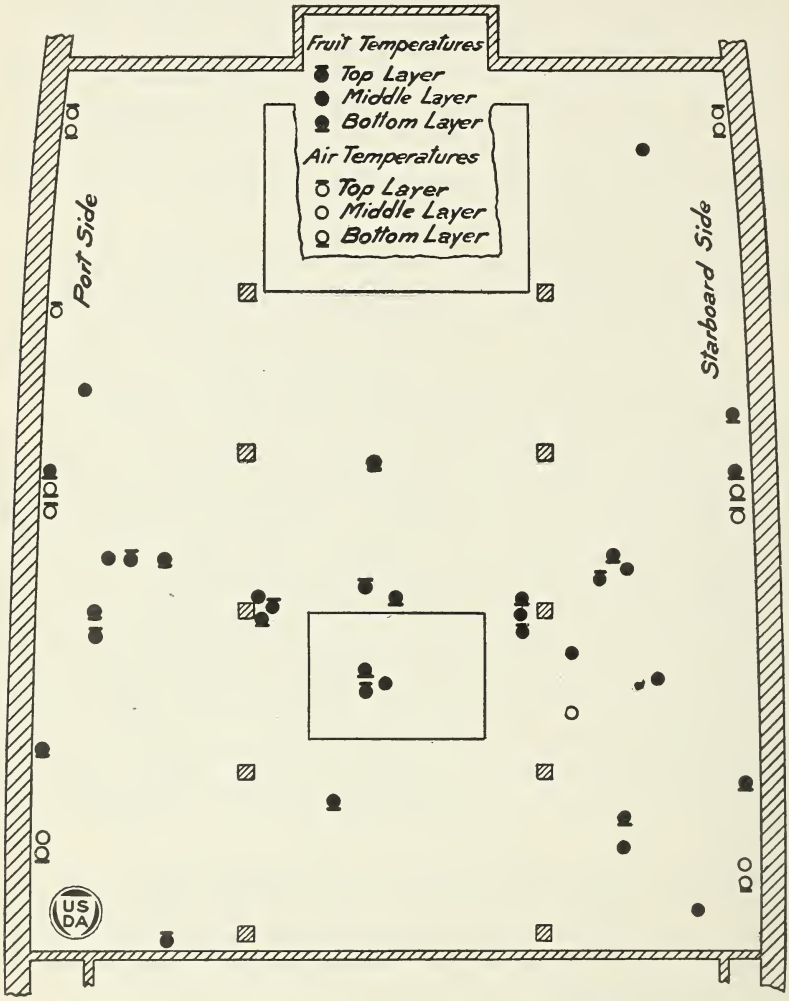

FIG. 3.—Diagram of No. 2 between-decks, showing locations at which temperatures were taken

eters in warm fruit and using the temperatures thus obtained in the averages. Not until the morning of the fourth day, as shown on the chart, was there any appreciable reduction in the temperature of the fruit. The gradual fall in temperature continued until the end of the trip, and on arrival the fruit registered 53° F. The lowest temperature on the third day, as shown on the chart, was 55° F., and not

until five days later, the ninth day, was the average of all the fruit temperatures taken in this hold down to this temperature again.

Referring to Figure 7, it is evident that where there was no interruption to the refrigeration and the hatches were not opened after

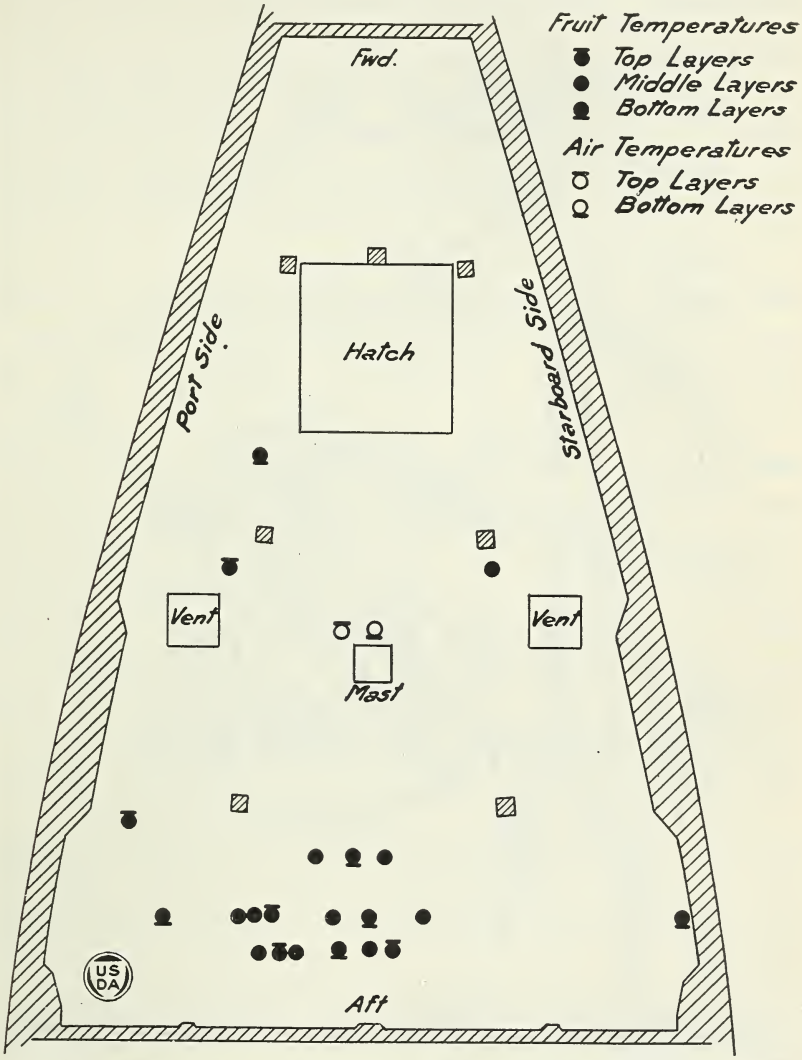

FIG. 4.—Diagram of No. 1 between-decks, showing locations at which temperatures were taken

the fruit was loaded, there was a relatively gradual reduction in the temperature of the fruit. This indicates that careful operation of the equipment is desirable in order to prevent the frosting of the brine coils, which necessitates the stopping of the machinery to warm them up and defrost them.

In Figure 6 the average ingoing and outgoing air temperatures in No. 2 between-decks are shown. Figure 3 indicates the positions at which these temperatures were taken. In Figure 5 the air in the mixing or suction chamber and the return air from No. 2 between-decks is given. The air from the mixing chamber is carried over the

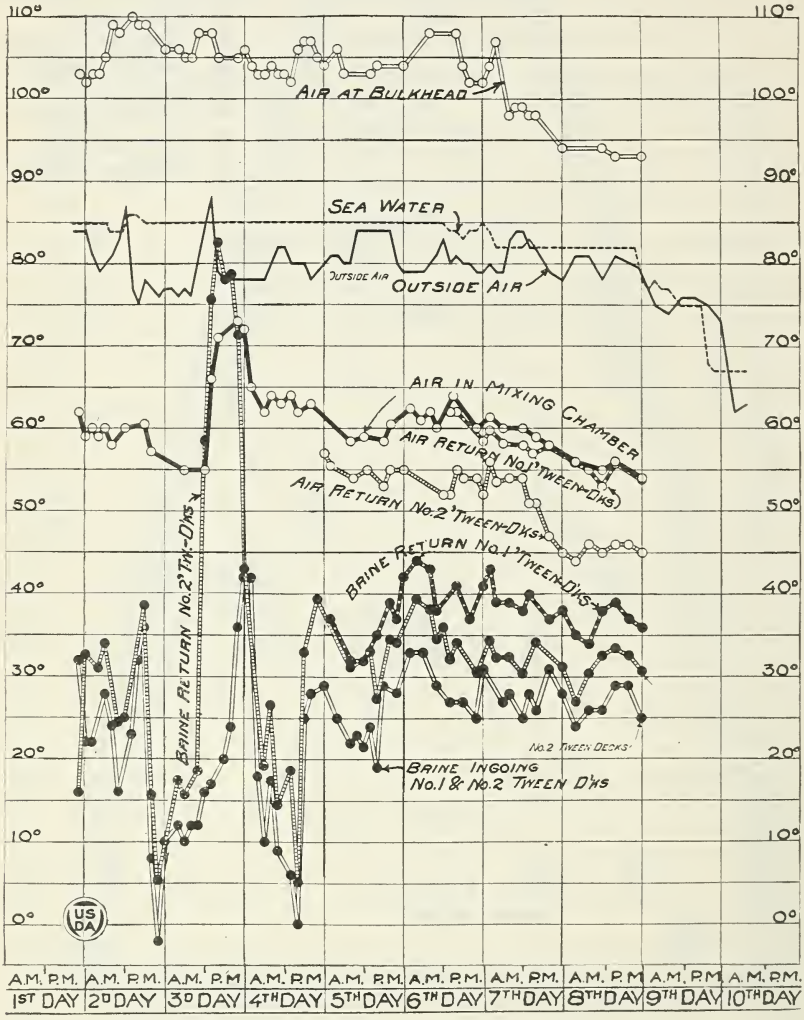

FIG. 5.—Air, sea-water, and brine temperatures on the first trip

brine pipes (see fig. 1) out into the hold. The air in this chamber, as shown in Figure 5, corresponds to the ingoing air in Figure 6 after it has passed over the brine pipes and just as it passes through the openings in the apron. The outgoing air, as shown in Figure 5, is the air after it has passed through, over, or under the load and is entering the openings in the apron prior to passing over the brine pipes on its return to the mixing chamber, where it is shown as "Air

return No. 2 'tween-decks." In Figure 6 an average difference throughout the trip of about 12 degrees between the temperature of the ingoing and outgoing air will be noted. In other words, the cold air was heated up 12 degrees by the fruit in the hold. The fruit lost this heat and was therefore cooled down, as is shown in the curve of average fruit temperatures (fig. 6). The temperature of the air was reduced and much of the heat removed as it passed over the brine pipes on its return to the mixing chamber. In this way an average of about 5 degrees of heat was absorbed from the air by the brine before it got back to the mixing chamber. There was an increase of from 5 to 7 degrees in the temperature of the air as it passed through the mixing chamber, as shown by a comparison of the air temperatures of the intakes and outlets. This in-

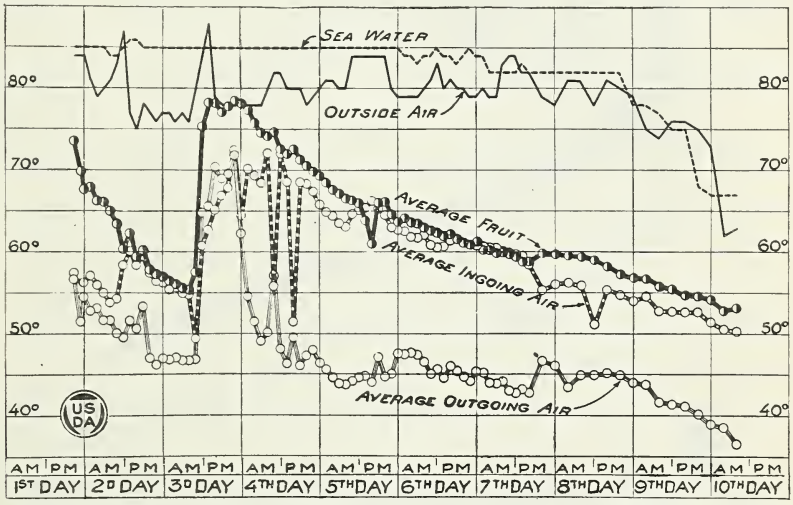

FIG. 6.—Average ingoing and outgoing air, average fruit temperatures in No. 2 between-decks, and outside air and sea-water temperatures on the first trip

crease was brought about through the friction of the fans and by heat which came through the bulkhead forming the outside wall of the mixing chamber. The air temperature was reduced 12 to 15 degrees after leaving the mixing chamber and passing over the brine pipes before it entered the hold.

The effect on the fruit of the temperature conditions obtaining in these two refrigerator holds was shown on the inspection of the cargo made on arrival at New York. The average percentage of rot in the oranges shipped under refrigeration, including uncultivated oranges, was 1.7 per cent, and with grapefruit it was considerably less, being below 1 per cent for the boxes inspected.

To obtain data on the value of refrigeration in the carrying of good fruit, eight boxes of oranges from a well-cultivated grove were shipped from San Juan to New York, four boxes being under refrigeration and four under ventilation. The results of this experiment show that the percentage of rot in the fruit under ventilation was 3.7, whereas with that under refrigeration it was 1 per cent.

From the above it is evident that there was more rot in the oranges shipped under ventilation than in those under refrigeration. There was, however, no large amount of rot in the fruit shipped under ventilation on this trip.

Further data as to the value of refrigeration in preventing rot in oranges transported from San Juan to New York were obtained by comparing the extent of the rot in a certain lot of fruit shipped under refrigeration on this steamer with an exactly comparable lot

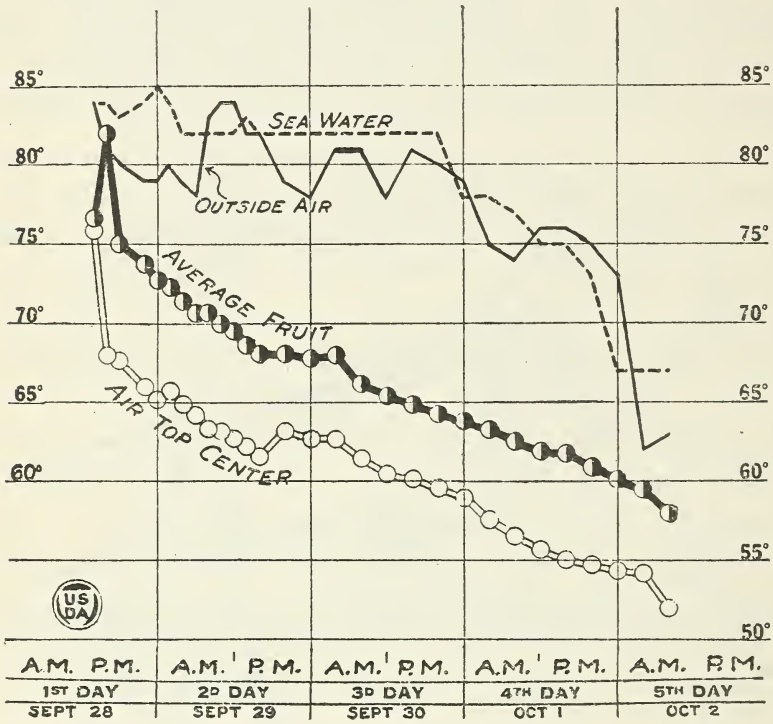

FIG. 7.—Average fruit temperature of fruit loaded at San Juan only and air temperature on No. 1 between-decks and the outside air and sea-water temperatures on the first trip

shipped under ventilation on another ship. The fruit under refrigeration arrived in New York with no appreciable rot, while that shipped without refrigeration showed 22 per cent of decay on arrival. These two lots consisted of 1,000 boxes or more, and the usual market inspections of both indicate a very appreciable benefit to the fruit from refrigeration.

The dunnage test and refrigeration of the compartments will be considered later.

THE SECOND TRIP

On the second trip the temperature-measuring instruments were again placed in Nos. 1 and 2 between-decks. There was, in addition to the fruit in the refrigerated compartment, a considerable quantity on deck and under ventilation in the holds, making possible further

comparison of the relative value of refrigerated and ventilated holds in carrying fruit from Porto Rico. Cold air was circulated over the fruit while loading at the different points around the island, which tended to prevent the fruit from rising in temperature after it was loaded. After the cargo was loaded and the hatches closed, the fruit was cooled down as rapidly as possible.

The average temperature of the fruit on the docks before loading was 80° F. The loaded fruit cooled down somewhat before the entire cargo was aboard, so that the fruit temperatures when first recorded are somewhat lower than the temperatures of the fruit on the docks. The average fruit temperature after the fruit was loaded was 73° F. and the final reading 54°, a difference of 19 degrees in five days, or an average lowering in temperature of 3.8 degrees per day. In the average air temperature there was a lowering of 26 degrees, from 68° to 42° F., in the same time, or 5.2 degrees per day. If the temperature of the fruit as it came on the ship is taken into consideration, there is of course more of a lowering in the temperature than noted above.

The extent of rot as determined by an inspection of the fruit carried under refrigeration and under ventilation is shown in Table 1.

TABLE 1.—*Decay in oranges and grapefruit under refrigeration, under ventilation, and on deck on the second trip from Porto Rico to New York*

[The inspection was made on the pier on arrival in New York]

Lot No.	Number of—			Decay (per cent)	
	Boxes	Fruits	Decayed fruits	Actual	Average
Oranges under refrigeration:					
1, cultivated	4	602	7	1.2	----------
2, cultivated	7	860	6	.7	----------
3, cultivated	3	644	4	.6	----------
Total	14	2,106	17	----------	0.8
4, uncultivated	2	416	5	1.2	----------
5, uncultivated	1	200	4	2.2	----------
6, uncultivated	3	526	38	7.2	----------
Total	6	1,142	47	----------	4.1
Oranges on deck:					
7, cultivated	2	238	12	5.0	5.0
8, uncultivated	8	1,441	146	10.1	10.1
Oranges under ventilation:					
9, uncultivated	3	502	137	27.2	27.2
Grapefruit under refrigeration:					
10, cultivated	4	294	1	.3	----------
11, cultivated	3	240	0	0	----------
12, cultivated	3	164	0	0	----------
13, cultivated	6	370	0	0	----------
Total	16	1,068	1	----------	.09
14, uncultivated	2	150	2	1.3	1.3
Grapefruit under ventilation:					
15, cultivated	4	288	1	.3	----------
16, cultivated	4	270	2	.7	----------
Total	8	558	3	----------	.5

It is evident from Table 1 that fruit carries well under refrigeration. In only one lot of oranges was there more than 2 per cent of

rot, and this was uncultivated fruit. The average percentage of rot in the refrigerated oranges was 1.9 per cent, while in the oranges on deck there was 5 per cent of rot in the cultivated fruit and 10.1 per cent in the uncultivated. In one lot of uncultivated fruit shipped under ventilation there was 27.2 per cent of decay. The grapefruit carried well under refrigeration and under ventilation, there being less than 1 per cent of rot except in one lot of uncultivated fruit.

To determine the effect of a longer time in transit than that now prevailing on the condition of the fruit on arrival at New York, a few boxes of fruit were loaded on the vessel on arrival in San Juan from New York. This fruit was carried around the island, back to San Juan, and thence to New York; in all it was 16 days under refrigeration. The results of this inspection are shown in Table 2.

TABLE 2.—*Decay in grapefruit and oranges shipped from San Juan, P. R., around the island, back to San Juan, and thence to New York*

[En route 16 days; inspection was made on the pier on arrival in New York]

Lot No.	Number of—			Decay (per cent)
	Boxes	Fruits	Decayed fruits	
Grapefruit:				
No. 1	3	198	0	0
No. 2	2	150	3	2.0
No. 3	3	240	7	2.9
No. 4	3	240	3	1.3
Total	11	828	13	
Average				1.5
Oranges:				
No. 5	3	611	12	1.9

From the results given in Table 2 it is apparent that there was little decay in either grapefruit or oranges during the 16 days they were on the ship. In one lot of oranges three boxes showed 1.9 per cent of decay, while that in the grapefruit ranged from nothing in lot 1 to 2.9 per cent in lot 3, with an average of 1.5 per cent. This experiment indicates that cultivated Porto Rican grapefruit could be shipped considerably farther than from San Juan to New York without undue deterioration.

THE THIRD TRIP

On the third trip temperatures of fruit were taken in No. 3 between-decks and No. 2 hold, two holds of very dissimilar shape. No. 3 between-decks was about 100 feet long from bulkhead to bulkhead in its greatest length, about 8 feet in depth, and about 52 feet at its greatest width. No. 2 hold was more nearly square in cross section, being approximately 50 feet at its greatest width and about 22 feet deep. The average temperature of the fruit on the decks was 80.3° F. at the time the first readings were made.

In No. 3 between-decks the average fruit temperature after the hatches were closed was 68° F., while the average from the last reading was 55°, a reduction of 13 degrees in six days, or a little over 2 degrees per day. In the No. 2 hold the fruit was loaded 15 layers high, which was more than twice the height in the other holds. It

was practically impossible with the equipment at hand to obtain fruit temperatures in all parts of the hold, but they were taken in all the layers. These measurements show that the fruit in the bottom layer was reduced to 45° F., a much lower temperature than in any of the other loads. The middle and top layers were reduced to 58° F. The average obtained for all the fruit temperatures at the end of the trip was 54° F. Inspection of the fruit on the pier at New York was made as usual. The results are shown in Table 3.

TABLE 3.—*Decay in oranges and grapefruit shipped under refrigeration on the third trip from Porto Rico to New York*

Lot	Number of—			Decay (per cent)	
	Boxes	Fruits	Decayed fruits	Actual	Average
Cultivated oranges:					
No. 1	7	1,328	0	0	----------
No. 2	2	350	3	.8	----------
No. 3	4	742	16	2.2	----------
No. 4	4	676	5	.7	----------
Total	17	3,096	24	----------	0.7
Uncultivated oranges:					
No. 5	24	4,338	36	.8	.8
Cultivated grapefruit:					
No. 6	11	760	2	.2	----------
No. 7	3	206	0	0	----------
No. 8	3	224	0	0	----------
No. 9	3	234	6	2.7	----------
No. 10	4	254	2	.8	----------
Total	24	1,678	10	----------	.5

It is evident from Table 3 that the amount of decay in the fruit was no greater on this third trip than on the other two trips. In the cultivated oranges the rot ranged from none to 2.2 per cent. In the uncultivated oranges the decay was only 0.8 per cent of those inspected. The average percentage of decay was 0.7 in the cultivated oranges. In the grapefruit the decay ranged from none to 2.7 per cent and averaged 0.5 per cent. No inspections were made on fruit shipped under ventilation.

THE FOURTH TRIP

The fourth and last trip of this series was made in the latter part of November. On this trip oranges and grapefruit were loaded from various points on the island, and as the cargo of fruit was not heavy most of it was loaded in No. 2 between-decks and the orlop or No. 1 lower between-decks. Temperatures were taken only in the orlop deck, because a fairly complete study had been made of the behavior of No. 2 between-decks under refrigeration in the earlier trips. The average temperature of the fruit when it was taken on the ship was about 80° F., practically the same as the average loading temperature of the fruit in the other three trips. In the orlop deck, owing to difficulty with the air-circulating system, the fruit cooled very slowly, and its average temperature was lowered from 76° F. when the first reading was taken, or from 80° if the temperature of the fruit at loading is taken into consideration, to 63° at the end of the voyage. For the time the temperatures were taken the

average cooling of the fruit was 13 degrees in six days, or 2.2 degrees per day. This reduction in temperature was not so great as in the case of No. 2 between-decks on previous trips and was probably because the air ducts to the orlop deck were none too large and in some cases offered considerable resistance to the passage of the cold air.

The fruit inspections on this trip showed slightly more decay in the oranges than was found in the inspections on the three earlier trips. The results of inspection are shown in Table 4.

TABLE 4.—*Percentage of decay in refrigerated fruit on the fourth trip on arrival in New York*

Kind of fruit	Number of boxes	Number of fruits	Fruits decayed	
			Number	Per cent
Cultivated grapefruit	5	342	0	0
Cultivated oranges	5	551	15	2.7

In addition to the inspections made at the dock from the general cargo of fruit, four boxes of oranges from the same lot were brought to New York, two under refrigeration and two under ventilation, then expressed to Washington and held there at a temperature of about 65° F. for a week from the time the ship was unloaded in New York. This interval was to approximate the time the oranges might be held at market temperatures before they were consumed. The results of this experiment are shown in Table 5.

TABLE 5.—*Comparison of percentage of decay in oranges of the same lot shipped partly under refrigeration and partly under ventilation and held one week after unloading*

Shipped under—	Number of fruits	Fruits decayed	
		Number	Per cent
Refrigeration	288	4	1.4
Ventilation	294	24	8.2

From the data in Table 4 it is evident that there was a slightly higher percentage of decayed oranges in this shipment than on the other three trips. All the grapefruit was in good condition. Table 5 indicates that this fruit shipped under refrigeration will remain in fairly good condition for a week after reaching New York. The difference in the amount of rot under refrigeration and ventilation is rather marked. This experiment alone is hardly sufficient evidence upon which to base definite conclusions, but taken in conjunction with other inspections made at the dock in New York it emphasizes the value of refrigeration for this fruit.

DUNNAGE TESTS

In the cooling down of a cargo of fruit from about 80° F. to a good carrying temperature it is obvious that the temperature of the fruit must be considerably lowered. Heat always flows from a warmer to a cooler medium, and the greater the difference in tem-

perature, other things being equal, the more rapidly the heat is transferred. It would seem, therefore, if the center of the cargo is to be cooled quickly provision must be made for the passage of the refrigerant, cooled air, in and around the boxes. It would seem also that the more open the stowage, so as to allow access of the air to the loading, the more quickly the fruit will be cooled down. Evidence on this point was gained in the dunnage experiments already mentioned, which were made on all four trips. The results of these

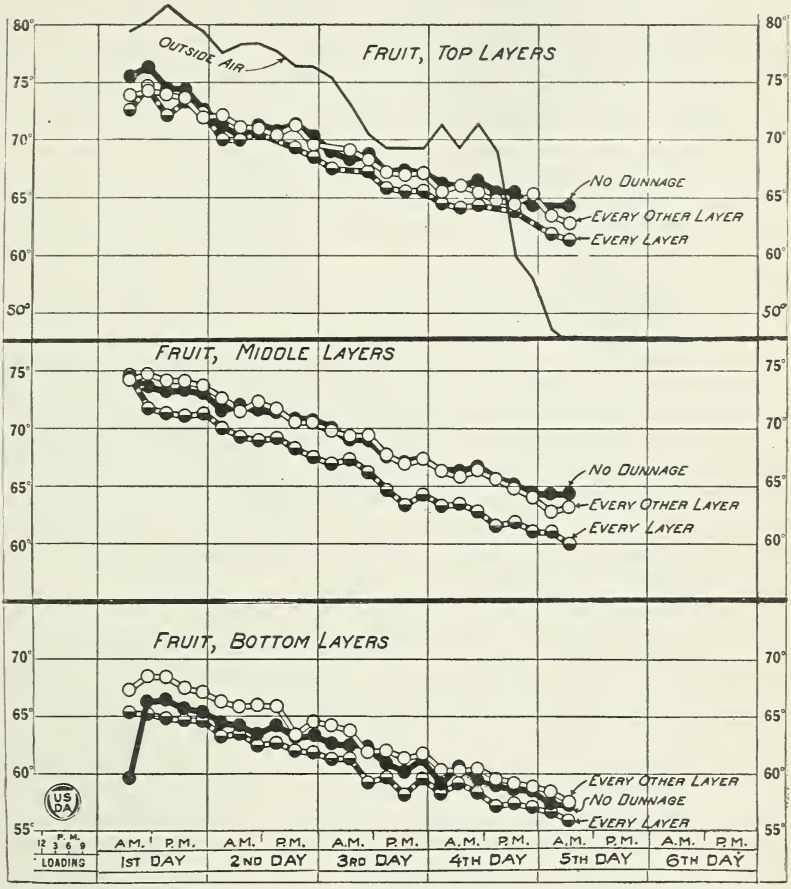

FIG. 8.—Average temperatures for four trips of the top, bottom, and middle layers of fruit in the dunnage test. Two different methods of placing dunnage are compared with fruit stacked without dunnage

experiments are shown in Figure 8, giving averages of all the tests. The fruit with which these experiments were made was loaded at several points on the island, the last point of loading being San Juan. For this reason the average fruit temperatures were calculated from readings made at the end of loading at this point. Had they been calculated from readings made at points of loading prior to this they would be misleading and not comparable, since readings made at an earlier date and under different conditions would have to be compared with readings made later on the trip.

The fruit temperatures in the top and bottom layers in the various stacks showed very slight differences (fig. 8), particularly in the loadings in which there was no dunnage and in which dunnage in every other layer was used. In both cases where dunnage was used in every layer, however, the temperature was lower than where either of the other methods of stacking was employed, though this difference was very slight. It is to be expected, particularly with the type of installation on the ship, that the fruit in the top and bottom layers, even though different methods of stacking are used, will be but slightly affected, owing to the fact that the racks with which the compartments are fitted allow a 4-inch air space between the deck and the bottom of the load. There is also considerable space between the top of the load and the deck above, which allows for adequate air circulation. The cold air as it issues from the sides of the hold readily passes over and under the load, coming in direct contact with the top and bottom layers; consequently, very little difference in temperature due to the use of dunnage can be expected at these points.

The difficulty in cooling the middle of a load of fruit, even in relatively small bulk, has long been recognized. This difficulty is increased in the ship's hold, where the bulk of the fruit confined in one space is large and in these experiments at a temperature of about 80° F. when loaded. There is no clear passage for the air to travel through the load, as there is under the floor racks and over the load.

It must be expected then that the fruit in the middle layer and in the center of the load will not be so easily refrigerated as that in the top and bottom layers, owing to the difficulty of securing adequate air circulation even when the air is forced through. Only by the use of dunnage can air channels be provided. Of course, methods of stacking could be worked out that would allow for air channels, but such methods would cause broken stowage and cut down the carrying capacity of the vessel.

The average temperature of the middle layers in which no dunnage was used (fig. 8) was reduced from 74° F. at San Juan to 64° at the end of the trip, a total average reduction of 10 degrees. Where dunnage was used in every other layer the reduction was 11 degrees, and where it was used in every layer the average lowering of the temperature in the boxes of fruit in the interior of the stacks was 14 degrees. In other words, the heat removed from the fruit was 40 per cent more where dunnage was used for every layer than where no dunnage was used and 27 per cent more than where dunnage was used in every other layer. This clearly shows the value of air space between the boxes, which can be provided by the judicious use of dunnage. There seems to be no question that the efficiency of the refrigerating equipment in cooling down fruit and holding it at the lower temperature is considerably increased by the use of dunnage for every layer.

The cost of dunnage for this purpose is not high, as it may consist of rough lumber 1 by 2, 1 by 3, or 1 by 4 inches and only 2 lineal feet are needed per box of fruit above the first layer. The dunnage can be used over and over again. Short lengths are very useful, especially in filling out at the sides of the hold and under hatchways where the cargo is to be broken out. The use of plenty of dunnage was found to be an inexpensive way of increasing the efficiency of the ship as a fruit carrier.

DISCUSSION OF RESULTS

The results of the experiments recorded in the foregoing pages show that with the type of refrigerating equipment described it is possible to cool down a cargo from 15 to 27 degrees by the time the fruit reaches New York. The fruit in some of the holds cooled down to a lower temperature than in others, probably because of the difference in arrangement and construction of the ducts through which the air is carried from the fan chamber to the holds. This cooling of the fruit was accomplished while the outside air and water temperature was about 80° F. It is probable that by increasing the size of the air ducts and eliminating short bends more cold air could be forced through the holds and the fruit cooled down more rapidly or to a lower temperature. There was, however, very little rot in the cultivated fruit carried from San Juan to New York under refrigeration when inspected on the pier at the end of the trip. The decay in practically all of the shipments inspected was less than 3 per cent, which, although constituting appreciable injury, does not necessitate repacking.

Some evidence was obtained in the experimental work on the effect of a longer carry than that from San Juan to New York. In one case grapefruit and oranges were carried under refrigeration around the island and then shipped to New York. In another, oranges were shipped to Washington after arrival in New York and then inspected a week later. Both shipments were in good condition. These are, of course, the results of only two experiments, but they indicate that some cultivated fruit at least might be forwarded from New York to other markets without entailing undue deterioration from decay.

Probably the most important point brought out in the experimental work was the result of the dunnage tests, in which it was shown that the interior of the load was cooled much more rapidly if it was stowed with dunnage so that the cold air could circulate on at least two sides of each box. In loading warm fruit in refrigerated ships where it is intended to cool it down, there is no question that methods should be followed similar to those which have been found to give the best results in cold-storage houses and precooling plants on land under similar conditions. Special attention must, of course, be given to certain features on ships, such as tying in the load so that it will not shift and economizing on space. It is possible that some other method of arranging the refrigeration coils and air ducts may be more economical of space than that employed on this ship, and some evidence has been obtained on this point, but inasmuch as it has not been tested experimentally it will not be considered here.

From the results of these four experimental trips there seems to be no question that good citrus fruit can be carried from San Juan to New York under the refrigerated conditions provided by this ship and be in good condition on arrival at New York; but, to accomplish this, the fruit should be handled carefully at the packing house, in loading and stowing on the ship, and should be placed under refrigeration as soon as possible after it is packed.

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